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Contents

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Cover: Fire shelter with section cut away to show fully equipped firefighter properly positioned. Fire shelters were heavily used during the 1985 fire season, especially on the Butte Fire. See articles beginning on p. 3 and p. 14.

Forest Fire Shelters Save Lives

Art Jukkala and Ted Putnam

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The 1985 fire season proved especially active for firefighters nationwide. Drought and adverse weather combined to set the stage for extreme fire behavior. Massive crowning, spotting, and fast spread characterized last year's fires, which trapped more than 200 firefighters. But thanks to good crew leadership and the fire shelter, many deaths and serious injuries were prevented.

Fires trapped crews in the East early in the year. Out West, the most dangerous fires took place later in the summer. Two serious incidents occurred in Idaho fires. Some 82 firefighters deployed shelters while battling the Lake Mountain Fire on the Payette National Forest. On the Butte Fire, in the Salmon National Forest, a fast-moving crown fire chased four crews into safety zones. The firefighters set up shelters and survived despite intense heat and smoke. According to one crew boss, the fire shelter made the difference: "The shelter saved our lives. We had no escape alternative."

Reports from the Lake Mountain Fire tell us that most firefighters deployed their shelters under circumstances that were not life threatening. Nevertheless, the shelter is credited with saving a few lives, and it protected countless crew members from serious burns and smoke inhalation.

Lives Saved on Butte Fire

The Butte Fire entrapments clearly were life threatening. Eddie Abeyta, crew liaison officer, Santa Fe National Forest, who was one of those trapped, says, "We would've never made it without the shelter. There is no question about it. No shelter, no walk out of there."

According to Nick Montoya of the Carson Hotshots, who was trapped in the larger of the two safety zones, "Mortality might have been 75 percent without the shelter." Of the 73 deployments in both safety zones, investigators believe at least 60 firefighters would have died without the shelter's protection. Once again the fire shelter had proved itself.

We estimate that the fire shelter has saved more than 140 lives since its introduction in the early 1960's. The main reason the fire shelter saves lives is because it gives firefighters a way to protect face and airways. Breathing flames and hot gases is the greatest hazard in fire entrapment; thus protecting face and airways is vital. This fact cannot be stressed enough. A Federal Aviation Administration study of 1,140 burn cases involving 106 fatalities concluded that if the lower respiratory tree (trachea, main bronchi, and secondary bronchi) is burned, death is almost inevitable.

We also believe the more you know about the fire shelter, the more confidence you'll have in it, and the better prepared you'll be to stay put in your shelter should you ever become trapped. We have learned a lot from our investigation of the Butte Fire entrapments and want firefighters to know about the role the fire shelter played and how they can increase their chance of survival.

What the Shelter Can and Can't Do

The fire shelter protects primarily by reflecting radiant heat. As demonstrated on the Butte Fire, even large cracks or tears do not reduce the shelter's protective capabilities when radiant heat is the principal hazard. Several people on that fire deployed shelters with 4- to 18-inch tears. These shelters let in some smoke but still protected their occupants from radiant heat and heavier concentrations of smoke.

The shelter's thin aluminum-glass cloth laminate can withstand only limited contact with flames. Cracks, tears, or holes reduce its protection in direct flames. The shelter should be deployed away from fuel concentrations—both natural fuels and flammable equipment.

Techniques for Survival

Avoid Entrapment—Experienced firefighters know the best way to ensure their safety on a wildfire is to avoid entrapment. But when drought conditions and severe fire weather combine, as they did on the Butte Fire, avoiding entrapment is not always possible. Several people we interviewed said that before being trapped on the Butte Fire, they felt they would never let themselves get into such a situation and need a fire shelter.

We estimate that the fire shelter has saved more than 140 lives since its introduction . . . .

Although entrapment can't always be avoided, you can make it unlikely by:

- Following the 10 Standard Firefighting Orders.
- Knowing the 13 fire situations that shout "Watch Out!"
- Knowing the four major common denominators of fire behavior that lead to tragedy or near-miss fires.

Use the fire shelter as a last resort. Follow proven escape procedures first.

Select Safety Zones Carefully—The large safety zones on the Butte Fire minimized direct flame contact on the shelters, allowing them to perform effectively and reflect radiant heat as they were designed to do.

First, select safety areas carefully. Next, look for natural protection within the safety zone and use it. Erect the shelter behind a large rock, dozer blade, or other heat shield. Take advantage of constructed or natural depressions or small earth berms. On roads, deploy in the cut slope ditch. Such spots expose you and your shelter to less heat, smoke, and wind.

Commit Yourself to the Shelter—When you know you can't escape entrapment, commit yourself to the shelter. Deploy it quickly. Use any extra time to pick the best spot and prepare the site by scraping away flammable fuels. Keep an arm or leg through one of the shelter straps. Otherwise, you might lose the shelter in the high winds the flame front generates. A survivor of the Butte Fire—a veteran of 23 fire seasons—estimated winds at 50 to 70 miles per hour.

The coolest, cleanest air is within a few inches of the ground. So stay low with your nose pressed to the earth.

Once inside the shelter, stick it out no matter how scared you are or how painful it is. Remember, it is always mueh better inside the shelter than outside. If you make a dash for it, your chances of survival are poor. If you leave after the flame front passes but while it's still smokey, you risk injury from smoke inhalation. It's best to stay put until a crew leader says it's safe to leave.

Maintain Communications—The entrapment reports we've studied show the psychological benefits of reducing fear and panic by talking to trapped coworkers directly or by radio. If you can't talk on the radio, listen. Outside observers may be able to provide valuable information about the fire in your location. At its peak, the noise of a fire can be deafening, and you may not be able to hear anyone. Don't panic. As soon as the noise subsides, resume communications.

Role of Other Equipment— Recent fire entrapments illustrate the value of flame-resistant clothing. This clothing protects you while you're escaping entrapment or deploying and occupying a shelter. Be sure to wear gloves. Butte Fire experiences show that holding the shelter down can be a major problem in high winds. Without gloves you may burn your hands and not be able to hold the shelter down. We hope to improve shelter hold-down features in future designs. Wear your hardhat, equipment packs, and other gear inside the shelter to help keep hot surfaces away from your body. Be sure to leave tools, which can cut shelter cloth, outside. Any gasoline or fusees should be left behind or thrown far from any shelter.

In larger safety areas, you may want to move the shelter to get away from heat concentrations. This tactic was effective on the Butte Fire. However, firefighters reported that as they moved the shelters were hard to hold onto, allowing smoke to get inside. *Remember, if you move, there is the danger of exposing your face to hot flames and gases.*

Shelter Training—The more you know about the fire shelter and what to expect during entrapment, the better prepared you'll be should it happen. A new film, "Your Fire Shelter;" is a good place to begin. Study the pamphlet of the same title carefully. Practice the imaging techniques, then get hands-on training by deploying obsolete shelters. Refer to the pamphlet for training recommendations.

Care and Inspection— Experiences during the past several years have shown why proper shelter care and inspection are vital. Many shelters deployed on the Butte Fire had cracks along the fold lines. Most shelters with this type of damage should be screened out in a proper inspection program. The pamphlet "Your Fire Shelter" contains details on care and inspection.

The events of the 1985 fire season have reaffirmed the worth of the fire shelter and the wisdom of having every firefighter carry one on the line. Entrapment experiences made believers out of many firefighters during this past fire season. Learn from their experience—find out as much as you can about how to use, care for, and inspect the fire shelter. This know-how could save your life someday. ■

Shelter Use Observations

1. Fire shelters work, even when they are not in the best condition. Some shelters used in the Butte Fire had 4- to 18-inch tears along folds.

2. In indirect attack situations, safety zones should be constructed to provide effective backup if alternative escape routes are cut off or early evacuation is not possible.

3. Safety zones on ridge tops should be at least 300 feet in diameter in timber with fuel model G or 10. They may have to be larger in other locations.

4. The value of competent, well-trained, and experienced crew bosses, strike team leaders, and division supervisors cannot be overemphasized. In the Butte Fire incident, many lives were saved through their actions.

5. Overhead should recognize that firefighters using shelters may not be able to use their radios if turbulent conditions make it difficult to hold the shelter in place. On the other hand, one-way communications should continue to give instructions and reassurance. It will be a challenge to overhead to effectively communicate reassurances to sheltered firefighters while still transmitting key information regarding the nature of a major incident.

6. When in shelters, firefighters should continue to talk to one another to maintain contact and reduce the chance of panic.

7. Once the fire has passed over, firefighters should stay in their shelters until the smoke has cleared.

8. Sheltered firefighters should not wet down their skin or clothing or wet handkerchiefs for breathing. Moist heat causes more damage to lung tissues than dry heat.

9. Sheltered firefighters should sip water to prevent dehydration.

10. Incident commanders, operation section chiefs, and emergency medical technicians should follow up after an incident to ensure that those involved in the shelter deployment are in the proper physical and mental condition to continue in their fire assignments. A delayed stress response following a traumatic incident could seriously impair the safety and productivity of fireline personnel.

11. The life-saving value of shelters should be ensured through proper care and handling by firefighters. Throwing shelters around, sitting on them, or other rough treatment will accelerate the development of tears and holes.

12. Missoula Equipment Development Center's field trial publication "Your Fire Shelter" (August 1984) contains the most up-to-date information on fire shelter use and inspection. All firefighting personnel should carefully review this publication. The publication includes information on entrapment and on deployment, inspection, and care and handling of the shelter.

13. Measures need to be taken to ensure that all firefighters know how to deploy and use the fire shelter. Contract sawyers, dozer operators, National Guard truck drivers, and other involved persons should be instructed as well.

Richard C. Rothermel and Robert W. Mutch

Methods for Predicting Fire Behavior—You Do Have a Choice

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Predictions of wildland fire behavior are used in various aspects of fire management: prescribed fire planning, presuppression planning, real-time fire suppression activities. Methods for calculating fire behavior covered here represent continued improvement of the packaging of mathematical prediction models for use by fire managers. Such improvement resulted from expanding user needs, additional research results, and new technology. Options available to managers range from manual methods (such as tables and nomograms), to handheld calculators, to computers. These methods mainly differ in prediction capabilities and ease of use. It is important to understand that although the methods may differ, all produce valid results.

In this article I will discuss the manual methods described by Rothermel in "How To Predict the Spread and Intensity of Forest and Range Fires" *(15)*, the TI-59 calculator with a CROM (Custom Read Only Memory) *(8)*, the HP-71B calculator with a CROM *(18)*, and the BEHAVE fire behavior prediction and fuel modeling system *(6, 7)* (fig. 1).

Figure 1—*Fire behavior predictions can be made using manual methods (such as nomograms or tables), the TI-59 and HP-71B calculators, or the BEHAVE fire behavior prediction and fuel modeling system.*

Computer programs not nationally available to all agencies and private firms, such as FIREMOD *(1)* and FIRECAST *(12)*, will not be discussed here. In addition, I have included only those methods that predict site-specific fire behavior. This discussion, therefore, does not include systems designed for other purposes, the National Fire Danger Rating System, for example. I will not cover the role and importance of experience, except to emphasize that it is vital to any method of predicting fire behavior.

Manual Methods

Manual methods for calculating fire behavior include tables, graphs, and nomograms. Albini's nomograms for spread rate and intensity *(2)* were the first step in providing prediction models to the field. As Dick Rothermel stated in the preface to "How To Predict the Spread and Intensity of Forest and Range Fires," Frank Albini "let the genie out of the bottle with publication of his book of nomograms in 1976." Although that was 10 years ago, the nomograms remain useful in this age of computers. Nomograms graphically depict potential fire behavior, showing relationships that cannot as easily be seen in tables. Nomograms allow quick estimation of spread rate, flame length, and intensity, based on a minimum of information.

Rothermel *(15)* describes the nomograms and other manual methods for calculating fire behavior that have been developed through the S-590 Fire Behavior Analyst (FBA) course. Even with the availability of calculators and BEHAVE, S-590 con-

tinues to include the manual methods. An FBA should be proficient in all methods of calculating fire behavior (manual, calculator, BEHAVE, and, of course, experience), so as to be prepared to cope with contingencies such as battery failure or lack of electric power.

The S-390 Intermediate Fire Behavior course *(13)* also covers manual methods. So many students take S-390 that it would be impractical to require all of them to use a computer or calculator. In addition, the S-390 Field Reference can be readily used in the field. The reference has been nicknamed the "two-bit TI," meaning that it can do what the TI does, at less cost.

TI-59 Calculator

Developing a spread and intensity CROM for the TI-59 handheld calculator gave users a quick, easy, and handy means for calculating fire behavior predictions in the field as well as in the office. The automation was a major step beyond manual methods.

Additional fire behavior prediction programs for the TI-59 are available on cards *(4, 11)*. This calculator can process calculations too complex for manual methods. For example, the nomograms for maximum spotting distance are limited to spotting from a single torching tree on flat ground. The TI program allows for mountainous terrain and for spotting from a group of torching trees, burning piles, and wind-driven surface fires.

BEHAVE System

The next improvement after the development of the calculator was the BEHAVE fire behavior prediction and fuel modeling system *(6, 9, 16)*. BEHAVE is currently being expanded to allow additional prediction capabilities *(7)*. Anyone who has progressed from nomograms to the TI and then to BEHAVE can attest to the extent of the advancement. BEHAVE is not only the most comprehensive of the methods for calculating fire behavior, but it is also the easiest to use.

Many of the prediction models in BEHAVE were already available in the form of manual methods or TI-59 programs. BEHAVE also includes models not previously available. One of the major features of BEHAVE is the capability to design custom fuel models.

BEHAVE gathers the prediction models into one easy-to-use package. Tables of predictions can be generated quickly. For example, in a few minutes one can tabulate the effect of various windspeeds on rate of spread, whereas it takes days to build tables using the TI-59. In the office, BEHAVE is the logical choice for fire behavior calculations.

However, despite improved capability to access computers from remote sites, handheld calculators are still needed for predicting fire behavior in the field.

HP–71B Calculator

The HP–71B calculator is replacing the TI–59 calculator for fire behavior calculations *(10, 18)*. The TI-59's are breaking down and are no longer manufactured. Handheld calculator technology has advanced significantly since the adoption of the TI-59 and its CROM. So the HP is much more than a replacement. Its capabilities go far beyond those of the TI and are almost the same as BEHAVE.

The HP fire behavior program is patterned after the BURN subsystem of BEHAVE (the FIRE 1 and FIRE 2 programs). The design, keywords, and worksheets are similar insofar as is practical. I anticipate that people will frequently switch between BEHAVE and the HP. For example, in fire camp an FBA may have access to BEHAVE, but on the fireline will use the HP.

Calculation Comparison

Table 1 shows aspects of fire behavior that can be calculated, and alternative methods for doing so. For example, forward rate of spread, if upslope with the wind, can be calculated using tables, nomograms, BEHAVE, and the TI-59 and HP-71B calculators. Only BEHAVE and the HP-71B, however, can calculate rate of spread for any specified direction. Containment by indirect attack can be calculated only by BEHAVE; this is the only calculation that can be done by BEHAVE and not by the HP-71B. The table also indicates that BEHAVE provides the only means for designing custom fuel models; the

Table 1—*Major elements of fire behavior that can be predicted and various methods of calculation [Numbers in parentheses refer to publications in the literature cited section.]*

Fire behavior element	Manual methods	TI-59	HP-71B	BEHAVE
Rate of spread; flame length; fireline intensity:				
Upslope with the wind	Tables *(13)*, nomograms *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
In the direction of maximum spread	vectoring *(15)*	—	CROM *(18)*	*(6)*
In any specified direction	—	—	CROM *(18)*	*(6)*
Heat per unit area	Nomograms *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
Reaction intensity	Nomograms *(2)*	CROM *(8)*	CROM *(18)*	*(6)*
Area; perimeter:				
With upslope wind	Tables *(13, 15)*	CROM *(8)*	CROM *(18)*	*(6)*
With cross-slope wind	—	—	CROM *(18)*	*(6)*
Length-to-width ratio	Diagrams *(13, 15)*	—	CROM *(18)*	*(6)*
Forward spread distance	Multiplication *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
Backing spread distance; maximum width of fire	—	—	CROM *(18)*	*(6)*
Maximum spotting distance:				
From torching trees	Nomograms *(15, 3)*	Card *(11)*	CROM *(18)*	*(6)*
From burning piles	—	Card *(11)*	CROM *(18)*	*(6)*
From wind-driven surface fires	—	Card *(11)*	CROM *(18)*	*(7)*
Containment (final fire size, line building rate, containment time):				
Direct attack	—	Card *(4)*	CROM *(18)*	*(6)*
Indirect attact	—	—	—	*(7)*
Scorch height	Graph *(2)*	—	CROM *(18)*	*(7)*
Probability of ignition	Tables *(13, 15)*	—	CROM *(18)*	*(7)*
Ignition component	—	CROM *(8)*	—	—
Fine dead fuel moisture	Tables *(13, 15)*	CROM *(8)*	CROM *(18)*	*(6, 7)*
Custom fuel models				
Develop	—	—	—	*(9)*
Use	—	Card *(9)*	CROM *(18)*	*(6)*

fuel models can then be used on the TI and HP.

Some factors related to individual predictions deserve further discussion. All methods for predicting fire behavior are based on Rothermel's spread model *(14)*. Therefore, given the same input, the predicted rate of spread will be the same whether the calculations are done using a nomogram, table, calculator, or computer.

Table 1 indicates that fine dead fuel moisture can be calculated using tables, the TI-59 CROM, the HP-71B

CROM, and BEHAVE. Nevertheless, there are major differences in the methods. The TI-59 estimates fine dead fuel moisture based on temperature, relative humidity, and shade. It should be used only as a last resort. The S-590 tables allow adjustment for other factors: aspect, slope, position on the slope, and time of day. The S-390 tables are a modification of, and produce results similar to, the S-590 tables. The prediction model implemented on the HP-71B and in BEHAVE is a highly sophisticated site-specific model *(17)*. The different input required for each of the models should tell the user that the models are indeed different.

The models used to predict factors other than fuel moisture are not dramatically different. Answers may be slightly different, but not significantly so, when one considers the application and the resultant decisions. In most cases input and output are the same. The differences lie in the internal workings of the mathematical model.

The vectoring method for predicting spread under cross-slope wind conditions includes some simplifying assumptions that permit the use of manual methods. More sophisticated calculations are done in BEHAVE and on the HP.

The area and perimeter calculations for the tables and the TI are based on a double-ellipse formula *(5)*, whereas BEHAVE and the HP use a simple elipse. The results are slightly different. This modification made it possible to link size calculations to containment calculations and to predict fire behavior in a cross-slope wind.

The containment calculations for the TI, HP, and BEHAVE are all slightly different. The TI model had limitations and discontinuities that were overcome for the BEHAVE version. The HP requires a tabular version of the model in BEHAVE because of the number of calculations involved.

Probability of ignition is the same for the tables, the HP, and BEHAVE. (The S-390 table is a condensation of the S-590 table.) Through oversight, ignition component rather than probability of ignition was put on the fire behavior part of the TI CROM. Ignition component was developed for use in the National Fire Danger Rating System; probability of ignition is used for fire behavior prediction.

Summary

Methods for estimating fire behavior vary from manual calculations to computer programs. Manually calculated predictions are subject to many limitations, and one must be highly trained to use them. Nevertheless, manual calculations will always remain useful, especially for a fire behavior analyst on a wildfire suppression overhead team. Those who need fire behavior predictions at a specified time will not accept the excuse of equipment failure. And when tailgate predictions of fire behavior are called for, a quick look at a nomogram should suffice.

Even with the availability of manual methods and BEHAVE, there has been overwhelming demand to replace the TI-59. Because of advances in technology, the HP-71B CROM has capabilities far beyond those of the TI-59 CROM. The HP-71B is very similar to BEHAVE, including a user-friendly interface. However, the availability of the HP-71B does not mean that each TI-59 should be replaced with an HP. Although the TI is capable of only about 10 percent of what the HP can do, if that 10 percent meets your needs and your TI is still working, there is no urgent need to immediately switch to the HP. The predictions from the TI are as valid as ever.

BEHAVE is at the automated end of the methods scale. It has the most capabilities and is the most user-friendly alternative. In most cases BEHAVE is the preferred choice; however, access to a computer is not always possible. Although predictive capabilities increase in the progression from manual methods to calculators to BEHAVE, each method for calculating fire behavior has its own niche in fire management activities. You are now fortunate enough to have a wide choice in the method that you use to calculate fire behavior. ■

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HP–71 Replaces TI–59 for Fire Calculations in the Field

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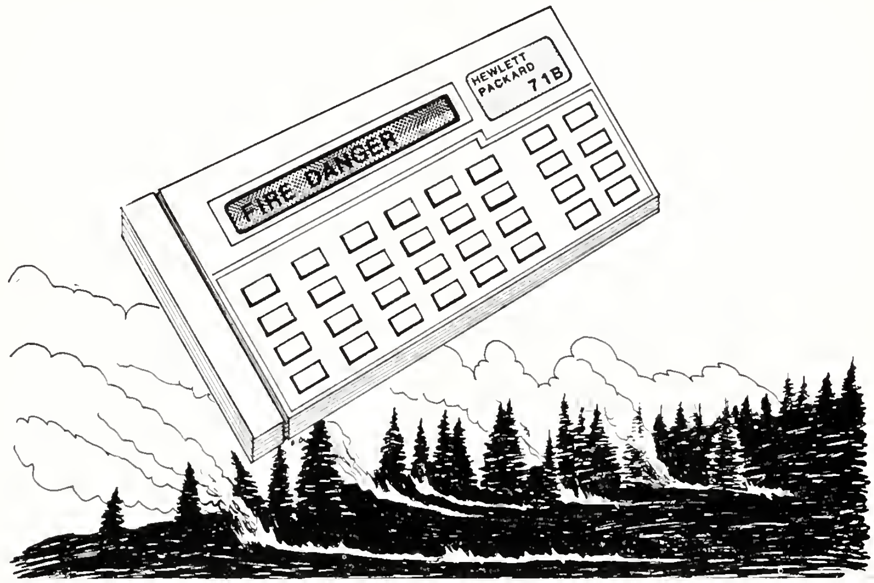
If your Texas Instruments TI–59 is nearing its last gasp, you can replace it with a newer calculator and enjoy the use of improved fire danger and fire behavior programs. The Hewlett-Packard HP–71B handheld calculator has been selected to replace the TI–59 and is now available on a USDA Forest Service contract.

The HP–71B has several features that make it attractive as a field calculator:

- An alphanumeric display that eliminates the need for keyboard overlays.
- A liquid crystal display (LCD) that becomes easier to read in daylight, rather than more difficult.
- Use of complementary metal oxide semiconductor (CMOS) technology, which has a very low power requirement, thus permitting 2 to 3 months of normal use between battery changes.
- Field-replaceable AAA batteries, rather than rechargeable nickel-cadmium batteries.
- A continuous memory that retains the information stored in the calculator even when it is turned off.
- A computational speed about six times faster than the TI–59.
- A capability to be used with optional battery-operated printers, data cassettes, and disk drives.
- A powerful BASIC programming language that is available for many other applications.
- Output that can be routed to a battery-operated, field-portable Hewlett-Packard inkjet printer.



The HP–71B has several features that make it an effective field calculator.

The National Fire Danger Rating System (NFDRS) program and the fire behavior program have been put on separate Custom Read Only Memories (CROM's) for use in the HP–71B. Separate user's manuals have also been prepared for each program. The manual for calculating NFDRS indexes and components is "Fire Danger Computations with the Hewlett-Packard HP–71B Calculator." The fire behavior user's manual is "Fire Behavior Computations with the Hewlett-Packard HP-71B Calculator." Both manuals are soon to be published by the Intermountain Research Station *(2, 4)*. Separate self-study guides have been prepared for the fire danger and fire behavior programs and are available through the agency coordinator.

NFDRS Program

The inputs required to perform 1978 NFDRS *(3)* computations are the same as for the TI–59 and other systems. Weather inputs may be recorded on the Weather Service's "10-Day Fire Danger and Fire Weather Record" form D–9b or on the form provided in the user's manual.

The major attributes of the NFDRS program are:

• Computes NFDRS indexes and components from weather inputs when the program's WEATHER module is selected.

• Automatically updates and stores the values of those inputs that must be carried forward from day to day. When the WEATHER module is used, these values do not need to be manually reentered each day.

• The NFDRS fuel models are stored in the calculator, not on magnetic cards.

• Up to five supplemental "user defined" NFDRS fuel models may also be permanently stored in the calculator memory, although no method currently exists for building and testing such models.

Fire Behavior Program

The fire behavior program, which is patterned after the BURN subsystem of BEHAVE *(1)*, implements much more fire behavior technology than was possible with the TI–59. Program capabilities are indicated by the following list of program modules and their functions:

• FUEL MODEL—permits inputting, loading, listing, saving and deleting models, and listing names of models stored in the calculator.

• DIRECT—calculates spread rate, heat per unit area, fireline intensity, flame length, reaction intensity, effective windspeed, and direction of maximum spread.

• SIZE—calculates area, perimeter, length-to-width ratio, forward spread distance, backing spread distance, and maximum fire width.

• CONTAIN—calculates length of fireline at containment time, time to containment, and final fire size or line building rate required to stop the fire at a specified size.

• SPOT—calculates maximum spotting distance.

• SCORCH—calculates scorch height.

• IGNITE—calculates probability of spot fire ignition.

• MOISTURE—calculates 1-hour timelag fuel moisture, fuel level temperature and relative humidity, percentage of area shaded, and probability of ignition for a specific burn time or on an hourly basis.

• MAP—calculates fire dimensions or spotting distance for plotting on a map.

• SLOPE—calculates slope steepness, elevation change, and horizontal distance between two points.

• WIND—calculates midflame windspeed from 20-foot windspeed.

• RH—calculates relative humidity and dew point from dry bulb and wet bulb temperatures and elevation.

• TWO—calculates weighted rate of spread for the two-fuel model concept.

Up to 19 user-defined fire behavior fuel models may be stored in the calculator, in addition to the 13 standard models that are always available. Output may be produced as a list of one to three values for each output item or up to a 3-by-3 matrix of output values for a single output item. Program modules can be linked as in the BEHAVE system, to easily pass outputs from one module to another for additional calculations. The program will accommodate either English or metric inputs and outputs.

Purchasing

The HP–71B calculator, fire danger CROM, and fire behavior CROM have been placed on contract for the following agencies: USDA Forest Service; USDI Bureau of Land Management, Bureau of Indian Affairs, National Park Service, Fish and Wildlife Service; and State Forestry agencies. Orders should be placed with:

Government Marketing Services, Inc.
701 E. Gude Drive
Rockville, MD 20850
Attn: Art Phillips

The original and one copy of the order must be sent to Government Marketing, and the order must state the contract number: 54–3187–5–35. Contract prices are:

Calculator	$349.12
Fire Danger CROM	37.80
Fire Behavior CROM	58.80

Those not authorized to purchase from this contract can order HP–71's and CROM's from Government Marketing at commercial prices.

The appropriate battery-operated printer is the HP "Think-jet" printer, model 2225B. The printer is not required for effective use of the calculator in the field because the user's

manuals include forms for recording inputs and outputs. The printer is almost a necessity, however, if the user plans to write other programs for the HP–71B. Ease of programming and filing capabilities suggest that many useful programs can be added to the HP–71B calculator. ■

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Behavior of the Life-Threatening Butte Fire: August 27–29, 1985

Richard C. Rothermel and Robert W. Mutch

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On August 29, 1985, 73 firefighters were forced into safety zones, where they took refuge in their fire shelters for 1 to 2 hours while a very severe crown fire burned over them. The incident took place on the Butte Fire on the Salmon National Forest in Idaho. Five firefighters were hospitalized overnight for heat exhaustion, smoke inhalation, and dehydration; the others escaped uninjured. Investigators estimated that without the protection of the escape zones and the fire shelters, at least 60 of the 73 firefighters would have died. Thanks to preparation of safety zones, the effectiveness of the fire shelters, and the sensible behavior of the firefighters themselves, disaster was averted.

Behavior of the Butte Fire, particularly its explosive movement on the afternoon of August 29, is of vital interest to fire behavior specialists, individual firefighters, and leaders who make tactical decisions based on fire behavior projections. That an already large and intense fire could rapidly escalate to even higher intensity—some have called it a firestorm—and move fast enough to overrun 73 firefighters warrants review by anyone concerned with fire management.

Immediately after the shelter incident, a review team was dispatched to the Butte Fire to document the meteorological conditions and fire behavior that contributed to the life-threatening run up Wallace Creek. Results of the analysis were distributed to all wildland fire management agencies early the following week. The review team was composed of Dennis Martin and Hank Walters, Forest Service Intermountain Region; Clyde O'Dell, National Weather Service; Dick Rothermel, Intermountain Fire Sciences Laboratory; and Bob Mutch, Forest Service Northern Region. The purpose of this article is to augment and expand the results of the initial review through additional interviews with those who had been on the fireline and an analysis of photographs taken during and after the fire run. Art Jukkala and Ted Putnam of the Missoula Equipment Development Center have also prepared a report on the performance of the fire shelter based on many interviews with those who used it on the Butte Fire. The article "Forest Fire Shelters Save Lives" in this issue includes information on their findings.

A separate review of the Butte Fire and adjacent fires in the Salmon River (termed the Long Tom Complex), conducted by the Forest Service Intermountain Region in October 1985, examined such topics as strategy, tactics, and other issues. The results of this review are on file in the Forest Service regional office in Ogden, UT.

Fire Environment

Severe drought characterized weather in the Butte Fire area throughout the summer of 1985, contributing to critically low fuel moisture levels. The fire weather station at nearby Indianola along the Salmon River measured only 0.31 inch of precipitation in June and 0.23 inch in July. Although more than half an inch of precipitation fell on two different days in early August, some of this as snow, only 0.12 inch fell between August 13 and August 31. At a remote automatic weather station near the fire, 1,000-hour fuel moisture readings from the National Fire Danger Rating System were rated at 8 percent prior to the run up Wallace Creek.

The weather on the Butte Fire from Monday, August 26, through Friday, August 30, was not unusual considering the location. Elevation at Base Camp was 7,400 feet; elevations on the fire ranged from 6,400 feet near the confluence of Wallace and Owl Creeks to 8,200 feet near the two safety zones. Typical late afternoon maximum temperature reached 70 to 78 °F, with minimum relative humidity in the 12 to 21 percent range at Sourdough Base Camp. The windiest period each day occurred between 1400 and 1500 mountain daylight time. The velocity was generally between 10 and 12 miles per hour, with stronger gusts. Inversions occurred each day, breaking between 1130 and 1330.

Weather on the day of the blowup, August 29, was not unusual, either. In the afternoon the temperature reached the mid-70's, and minimum relative humidity was in the upper teens. At base camp, low-level winds were out of the south at 8 to 12 miles per hour in the afternoon, with occa-

sional gusts to 17 to 20 miles per hour. District personnel reported that fuel loadings ranged from 80 to 100 tons per acre in spruce-fir stands in drainage bottoms, to 25 to 40 tons per acre in higher elevation lodgepole pine-fir stands. Fuel models 8 and 10 characterized most of the Wallace Creek drainage.

One unusual feature of the area threatened by fire was the topography. The upper slopes did not converge into sharp peaks as is commonly the case in the Rocky Mountains, but tended to be domelike, with continuous crown cover. Wallace Creek itself was a well-defined north-south drainage that became progressively steeper at its headwaters near the two shelter sites.

General Fire Behavior

The Butte Fire was started by lightning on July 20, 1985. This fire was part of the Long Tom Fire Complex in the Salmon River drainage, which included the Corn Lake, Bear, Fountain, Goat Lake, and Ebenezer Fires. The Butte Fire was first contained on August 5 at just over 20,000 acres. Strong winds fanned smoldering fuels and spread fire across control lines on August 24 and 25. Fire activity peaked on August 27, 28 and 29, as the fire made runs of 1,000, 2,000, and 3,500 acres, respectively. About 3,000 of the 3,500-acre growth on August 29 reportedly occurred in about 90 minutes. It was during this run up Wallace Creek that the 73 firefighters deployed their fire shelters. Simultaneously, another run of lesser severity occurred in Owl Creek, the drainage east of Wallace Creek. Both columns were characterized by dense black smoke. By midafternoon the Wallace Creek column had reached 15,000 to 17,000 feet above terrain and had a firm cumulus cap. Another area of intense fire activity took place on the western flank where the fire spread northward but was apparently pulled into the main fire in Wallace Creek.

Events of August 29

On August 29 wind velocities were not especially high. In the early afternoon, eye level winds were measured at 7 to 8 miles per hour at the confluence of Owl Creek and Wallace Creek. At the higher elevation near the head of Wallace Creek, the local winds were stronger. Division Supervisor Jim Steele estimated winds to be 10 to 15 miles per hour, with gusts to 20 miles per hour across the ridges. Measurements nearby confirmed this estimate, but with gusts of 25 to 30 miles per hour.

Figure 1 shows the fire area at 0200 in the morning on August 28, the day before the big run, and its extent by 2200 in the evening. By 0200 in the morning of August 29, the fire had spread considerably further, having crossed the lower end of Wallace Creek and moved up the ridge toward Owl Creek. The burned areas in lower Wallace Creek were patchy. Of special importance on the morning of August 29 were the spot fires in the middle portion of Wallace Creek and along Owl Creek at the southeast corner of the fire.

An understanding of the fire control operations is essential to understanding many events during the 29th. Having had little success at close-in direct attack on the 26th and 27th, the overhead team had decided to use an indirect attack strategy. On the 28th and 29th, a tractor line was built along the main ridge on the north end of the fire, approximately 1.5 miles north of the nearest spot fires in Wallace Creek (fig. 1). Fortunately, the line construction included several safety zones 300 to 400 feet in diameter at approximately 1/4-mile intervals. The plan for the 29th was to conduct a burnout operation in the late afternoon when humidity was expected to rise. An aerial drip torch would be used for center firing in the upper end of Wallace Creek. Crews were to be dispersed along the line to burnout from the line after a convection column was developed.

During the morning of August 29, spot fires near the confluence of Wallace and Owl Creeks threatened valuable timber and seemed to have the potential to outflank the control line to the east. Thus, it was decided to use the helitorch early in the day to burn out and stabilize the line in this area. Initial attempts began just to the north of Owl Creek (marked A on fig. 1) about 1200. The area did not burn very well, and ignition attempts were repeated. Bill Williams, the operations chief, reported that this fire was ineffective at developing a significant

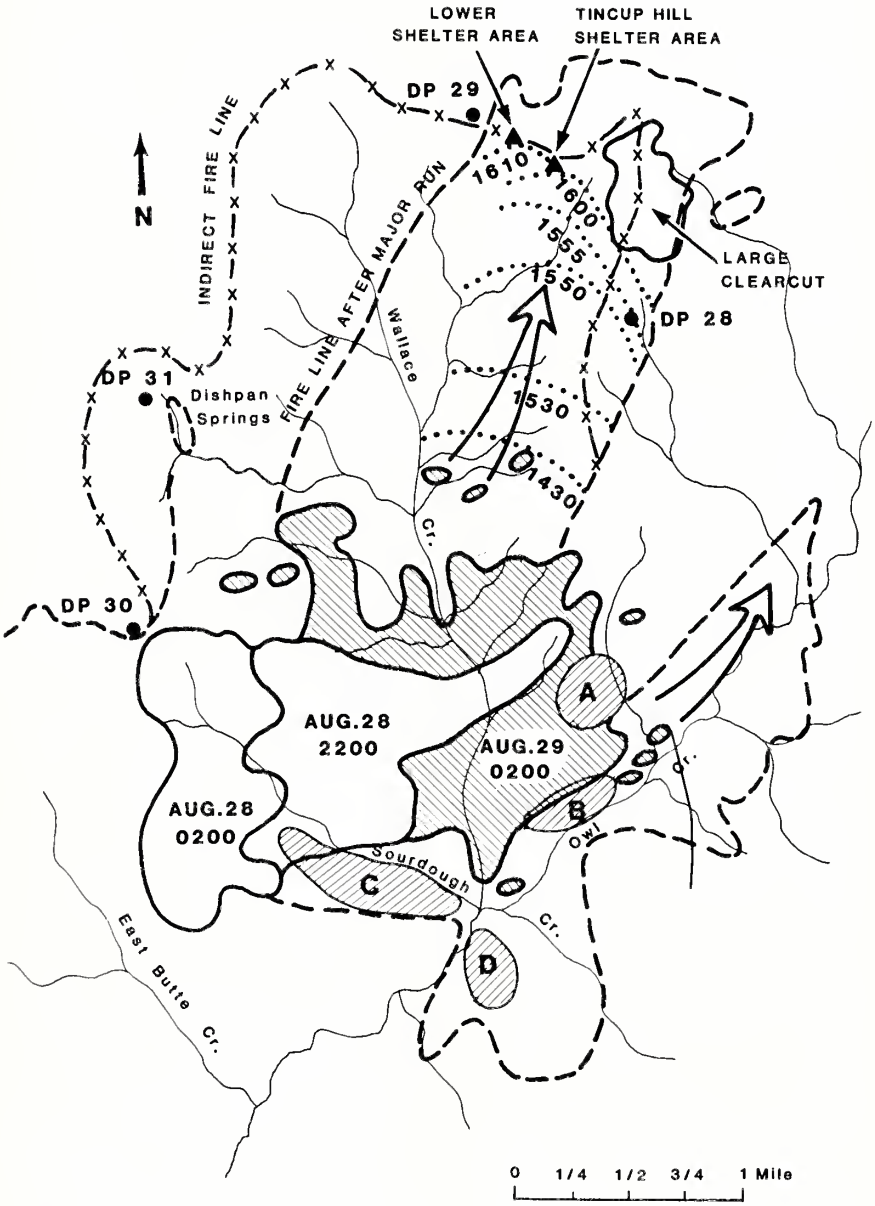


Figure 1—*Arrows depict major fire runs on the Butte Fire during the afternoon of August 29, 1985. The 73 firefighters deployed fire shelters at the lower shelter area and Tin Cup Hill shelter area. Areas A, B, C, and D indicate where the helitorch burnout operation was conducted that afternoon.*

fire column necessary for improving the fireline.

While attempts to burn out line near Owl Creek were in progress, the fire was developing strength in lower Wallace Creek. Three reports substantiate the development of fire in Wallace Creek. Bill Williams reported a large convection column east of Dishpan Springs. Dave Broberg, division supervisor in Owl Creek, reported two strong columns developing, one near drop point 30 at the upper end of Sourdough Creek and the other east of Dishpan Springs. Gary Orr, the division supervisor on the west side at drop point 30, saw the fire east of him throwing firebrands into Wallace Creek. Orr reported that the fire in this area was becoming active around 1100.

The spots along Owl Creek also became active and developed a strong convection column by 1300 (fig. 2). Smoke from these spots and from the helitorch fire was moving to the north. It appeared to some that these columns were being pulled to the north by the larger column developing to the northwest. With the aid of indrafts to these columns, the helitorch was used to burn out hand line and dozer line in areas C and D near the confluence of Sourdough and Owl Creek.

Meanwhile, Gary Orr at drop point 30 reported lots of fire in lower Wallace Creek. Considerable red coloration could be seen in the smoke columns, and at 1300 or 1400 the fire

Figure 2—*Convection column development near the confluence of Sourdough, Wallace, and Owl Creeks at about 1515 m.d.t. on August 29. These columns originated from spot fires and helitorch operations.*

was intensifying and moving up Wallace Creek.

The helitorch continued burning out the line in area C. Later, at approximately 1500, area D was burned according to Bill Williams and Dave Broberg. Photographs looking north taken from a helicopter just to the south of the convergence of Sourdough, Wallace, and Owl Creeks (fig. 2) show the smoke columns building at about 1515. From this vantage point, the strongest column was from the burnout operation and spots in Owl Creek. All of the smoke was moving northward up Wallace Creek. The firing operation at the south end of the fire was completed successfully about 1550, and the fire was contained along the southern line just as it was reaching full strength in upper Wallace Creek.

Wallace Creek Run

About 1515, Jim Steele, at the northeast end of the fire, who later

went into his shelter at Tin Cup Hill, reported that he was walking on the trail above the large clearcut and could see fire coming up over a ridge to the south. He reported that at that time he could not see fire in Wallace Creek because of intervening smoke and trees. The fire he saw to the south was probably coming out of Owl Creek.

Bill Williams reported that about this same time a large, strong convection column was standing over the fire. This column was within the main northern dozer line, and Bill still hoped to use indrafts from the column to complete the planned burnout in upper Wallace Creek. Because a very severe crown fire started moving to the north up Wallace Creek on a western exposure (the east side of Wallace Creek) through extremely heavy fuels, the helitorch was never used in this area as originally planned.

Gene Benedict, the incident commander, was returning to the fire by helicopter between 1500 and 1515 and reported that "while viewing this fire I had three other convection columns in view: Goat Creek on the Salmon National Forest, Hand Meadows on the Payette National Forest (a new start), and a fire on the Nezperce near Cotter Bar. All fires were extremely active with apparent strong convective activity and substantial rates of spread, except for Goat Creek, which was topographically confined."

After landing, Gene received reports that the fire in Sourdough Creek had moved into Wallace Creek and had started a firestorm.[1] Initial reports said it covered about 2 miles in 15 minutes. (This later proved to be an overestimation.) Right after the major run, a second run started on the west side near drop point 30, apparently outside the dozer line. Initially, it spread rapidly to the north, but then veered to the east, probably due to indrafts from the larger column in Wallace Creek. This secondary run threatened firefighters along the line on the west side, who were evacuated by pickup truck and helicopter. Although this rescue was overshadowed by the fire shelter deployment, it was nevertheless an intensive effort accomplished safely.

Neal Davis, air attack supervisor, flew by helicopter around the fire just after 1400 and again at 1515. He provided estimates of the fire location in Wallace Creek before the fire developed the extreme behavior reported later. On his next flight, at 1550, Neal saw the firefighters in the safety zones preparing to go into their shelters.

Firefighter Steve Karkanen, working between drop point 28 and the large clearcut at the head of Wallace Creek, recorded the movement of the crown fire as it progressed up Wallace Creek. Steve took color photographs of the fire, recording his location, the direction he was shooting, and the estimated time and location of the fire front. His notes were especially helpful in reconstructing the fire movement. His notes at 1600 describe the nature of the fire as it passed around the large clearcut:

> Experiencing intense heat and high winds from all directions. At least three large whirlwinds passed over that were strong enough to knock people off balance. The area became too smoky and dusty to take photos. The smoke column completely enveloped everyone, and it was impossible to see the fire. Visibility was reduced to zero several seconds at a time, the air was very hot, and the area was showered with burning embers. Personnel within the clearcut did not take to their shelters, a dozer was used to build fireline around the vehicles, and the pumper crew worked on small spot fires in flashy fuels.

Personnel at the lower shelter area reported that the fire reached them at 1610. Jim Steele reports that the firefighters on Tin Cup Hill went into their shelters approximately 10 to 12 minutes before those in the lower area did. This would have put them in their shelters at just about 1600, or a couple of minutes before. Steele further reports that the fire approached them at about 1545 out of a draw to the southeast. While Steele was preparing to get into his shelter, he talked by radio to Strike Team Leader Ron Yacomella at the lower shelter

[1]Although referred to as a firestorm, it should more properly be called a conflagration, which is a severe spreading fire. The term "firestorm" is normally used to describe a severe stationary fire or burnout of an area within a conflagration.

area approximately 1,000 feet away. Ron asked if he should start his backfire at this time, which he did. His crew burned out approximately 200 feet in front of the lower shelter zone before the fire hit at 1610. Their backfire started easily. At first strong indrafts pulled the fire and smoke toward the fire front, but later the smoke blew back over the crew.

Table 1—*Behavior of Wallace Creek fire run on the afternoon of August 29, 1985*

Time period	Elapsed time	Distance	Rate of spread	
	min	*mi*	*mi/hr*	*ch/hr*
1430–1530	60	0.32	0.32	26
1530–1550	20	0.48	1.45	116
1550–1555	5	0.29	3.48	278
1555–1600	5	0.14	1.68	134
1600–1610	10	0.15	0.90	72

The Nature of the Fire

From observations by Neal Davis, Steve Karkanen, Jim Steele, and Ron Yacomella, we have reconstructed the probable location and time of the fire front as it moved up Wallace Creek and overran the crews (fig. 1). The rate of spread during the run is derived by scaling the distances from the map at each time line.

It appears that up until about 1530, although crowning and developing strong convection columns, the fire behavior was similar to the behavior observed on the two preceding days (table 1). The spread rate was low, about ⅓ mile per hour. After 1530 the fire spread much faster, with an average rate of about 2 miles per hour and a maximum of about 3½ miles per hour. This period was described as a firestorm by observers. The fire had to travel slightly over 1 mile in half an hour to reach the safety zone. In order for the firefighters to reach the large clearcut from the lower safety zone, they would have had to begin the evacuation by 1530.

As with any fire, this one must have moved by surges, with some periods of little or no spread. The reconstructed spread rates are too coarse to show the surges and appear to be slower than the impression received by observers on the ground.

Jim Steele reported that on Tin Cup Hill, firefighters in their shelters were hit by three waves of fire, the first one from the southeast. The second one burned up the north side and then burned back towards them at about the same time as the people in the lower safety zone were going into their shelters. The third wave hit from the southwest. Each time they were hit by a new wave of fire, the firefighters moved, crawling along the ground inside their shelters searching for cooler areas of the safety zone. At one time they moved away from the dozer piles of slash that had been made during the clearing of the safety zone. After 40 minutes in their shelters, they came out, but dense smoke forced them back in again for another 30 minutes. The air entering the shelters around the lower edges was apparently remarkably free of smoke.

The fire that overran the crews was very large and very intense. Figure 3 shows the nature of the fire as it passed over the shelter and indicates the size of the column in comparison to the trees. In the original color slide, the convection column shows red coloration for hundreds of feet above the trees. The fire at this time was almost certainly an independent crown fire *(4)*.

Viewed from the front, the fire appeared as a wall of flame 200 to 300 feet high. Viewed from the air, ahead of the fire, the flames were estimated to be two to three times the tree height. The fire front was advancing as a typical standing flame with the base of the fire in the trees. The flames in the front were not seen to be rotating or turbulent. The smoke was rising sufficiently so that the flame could be seen clearly. The column rose nearly vertically, then tilted toward the north. The rear of the column was a turbulent, swirling mass, impressive in its extreme behavior.

After the run, aerial inspection of upper Wallace Creek revealed a large, intensely burned area in which all crown needles and smaller surface fuels were essentially gone. There

Figure 3—*A view of the fire as it reached upper Wallace Creek and overran the fire crews. The crews deployed their fire shelters in safety zones similar to those seen in the foreground. This photo was taken from a helicopter looking toward the east.*

was, however, no evidence from the air, or on the ground near the shelter sites, of firestorm activity such as that seen on the Sundance Fire in the Idaho Panhandle in 1967. Trees were not laid down in patterns that would indicate large firewhirl activity. Some firewhirls had been observed during the fire, but trees were not knocked down, uprooted, or broken off as they were in the Pack River Valley as a result of the Sundance Fire.

Inside the Fire Shelters

That all the firefighters in the escape zones survived without serious injury borders on the miraculous. Nevertheless, the approach and passage of the fire was a terrifying ordeal. Many, in fact, doubted that they would live through it. The trauma of the event was reflected in interviews with the survivors.

Witnesses, all of them experienced firefighters, said that this was no ordinary crown fire. To some it was a

Passage of the flame front was accompanied by a roaring sound, like that of a jet airplane ....

standing wall of flame that reached 200 feet above the treetops. Others described it as a huge, rolling ball of fire with a bright orange glow. Some witnesses reported large balls of exploding gasses in the flame front.

Passage of the flame front was accompanied by a roaring sound, like that of a jet airplane or a train. One firefighter found this the most frightening part of the ordeal: "The noise builds up until you can't hear yourself think and then the ground begins to shake." He estimated that the shaking and roaring lasted 10 minutes. Over the roar of the fire he could hear the shouts of nearby firefighters screaming for reassurance, followed by shouts of encouragement from other firefighters.

Strong, fire-induced turbulence made it difficult to deploy shelters and keep them down. One witness reported a feeling of weightlessness, of being lifted off the ground. Another reported the shelter being slammed down against his legs. Within the safety zones, everyone moved as far as possible from the flame fronts by crawling along under the shelter.

Within the shelters, firefighters experienced extreme heat for as much as 10 minutes. Shelters were so hot that they could only be handled with gloves. Light entering the shelter through pinholes changed from dark red at peak intensity, to orange, to white, as the fire passed over. One survivor said that at one point the ground looked as though it had been painted a bright orange. Firefighters learned to evaluate the color of the light as an indication of the fire's intensity in order to judge when it was safe to come out of their shelters.

After leaving the shelters, some firefighters showed symptoms of carbon monoxide poisoning: vomiting, disorientation, difficulty in breathing. Emergency medical technicians administered oxygen to several individuals; five were evacuated to a hospital for treatment and observation. All fully recovered.

Among those interviewed, the consensus was that without the shelters none would have survived. A firefighter with 20 years' experience summed it up as follows: "The most frightening, scariest experience I've ever had. The fire was over us, around us, everywhere. I was in Vietnam for a year, but this beats it all."

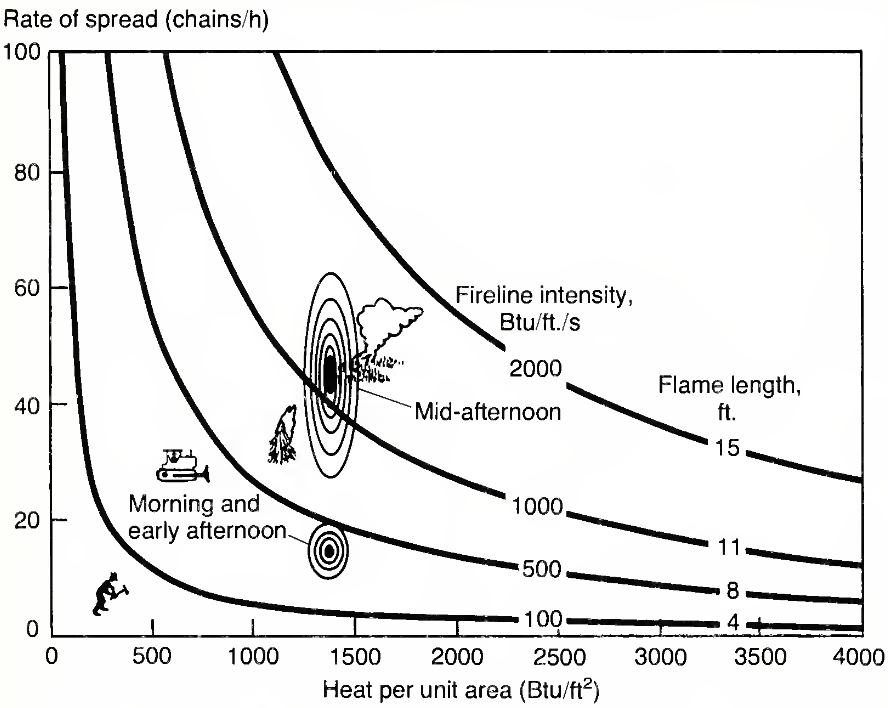
Factors Contributing to Fire Behavior

Fire activity in the preceding days contributed to the ease with which the fire in Wallace Creek began. Fire behavior on the afternoon of Thursday, August 29, was a repeat, albeit a much more severe repeat, of the fire behavior of the preceding two days. Each day took out more acreage and consequently left a larger holdover fire for the following day. On the morning of the 29th, the north edge of the fire was uncontained. Fuels were burned in patches, leaving large amounts of scorched fuel and trees within the fire area. The continuous fuels and lack of topographic barriers allowed the fire to move up the slopes of Wallace Creek with only moderate winds. The topography contributed substantially to the fire behavior and difficulty of control. The slopes from the valley bottoms were steep, contributing to rapid upslope runs; the ridge tops were rounded and covered with continuous fuels. Hence, there were no definite fire barriers such as steep rocky slopes, sharp ridges, or scrubby subalpine fuels.

Examination of weather records failed to reveal any factors that would have contributed to the large-scale convective activity observed on August 29. The extremely dry spring and summer probably contributed to the rapid spread of the fire and difficulty in controlling it. As on other fires in the northern Rocky Mountains at that time, tree crowns were extremely easy to ignite. Certainly the dry fuels on the ground also contributed, although the major fire runs at this elevation (6,000 to 8,000 feet) carried predominantly through the crowns.

Fire Behavior Analysis

Postfire analysis of the potential fire behavior in surface fuels was made with the BEHAVE fire prediction system *(1)* and displayed on the fire characteristics chart (fig. 4). Fuel model 10 was used. The values for fuel moistures ranged between 3 and 7 percent. The light winds of the



morning and early afternoon would have produced fireline intensities of 250 to 500 Btu/ft.sec, making the fire difficult to control. The stronger midafternoon winds would have produced fireline intensities in the surface fuels of 600 to 1,500 Btu/ft. sec, virtually assuring an uncontrollable crown fire. The range of the conditions is shown by the ellipses on the fire characteristics chart. The inputs to BEHAVE and the outputs produced are shown in table 2.

The calculated rate of spread in the surface fuels was 11 to 19 chains per hour in the morning and early afternoon. The higher windspeeds in midafternoon would have pushed the rate up to 28 to 57 chains per hour. We do not have methods for calculating crown fire rate of spread, but it has been found that crown fire spread can be 2 to 4 times faster than the rate of spread calculated for fuel model 10 in fuels exposed to the wind and as much as 8 times faster if the fire is going up steep slopes *(2)*. If we compare the calculated rate of spread in the surface fuels with the crown fire values given in table 2, we find that for the period 1430 to 1530 the crown fire was 1.4 to 2.3 times faster than the surface fire. In late afternoon, from 1530 to 1610, the crown fire was 2.6 to 5.3 times faster. These values fall within the suggested range mentioned above.

There is a great deal of uncertainty in this type of calculation, indicating a strong need for research on crown fire behavior and better guidelines for predicting the onset and spread of crown fires and potential blowup situations.

Conclusions

The type of fire run observed in upper Wallaee Creek on August 29 was not unusual for fires in lodgepole pine during the 1985 fire season throughout the northern Rocky Mountains. The high-intensity fire runs were the result of drought-induced, extremely low fuel moistures in all size classes and the speed of the transition from surface fires to torching, spotting, and crowning fires. Because large areas were burning unchecked by either fireline or natural barriers and a southerly gradient wind had reinforced upslope and upcanyon afternoon winds in Wallace Creek, the direction of fire spread and crown fire development before 1530 were not a surprise. The distance the fire spread from 1530 to 1600, and its severity,

Table 2a—*Data used in BEHAVE to assess fire behavior in surface fuels on the Butte Fire*

Element	Data
Fuel model	10
1-hr fuel moisture	3 to 7%
10-hr fuel moisture	6%
100-hr fuel moisture	9%
Live woody moisture	75%
Midflame windspeed:	
Early afternoon (sheltered)	4 to 6 mi/h
Midafternoon (exposed)	10 to 15 mi/h
Percent slope	45%
Wind direction	Directly uphill

Table 2b—*BEHAVE outputs*

Time	Rate of spread	Heat per unit area	Fireline intensity	Flame length
	chains/hr	*Btu/ft²*	*Btu/ft.sec*	*ft*
Early afternoon	11–19	1286–1487	251–523	5.7–8
Midafternoon	28–57	1286–1487	664–1563	8.9–13.3

were, however, unexpected. The large area of holdover fire adjacent to continuous timber with heavy surface fuels proved to be a juxtaposition capable of generating an incredible amount of energy in a short time.

Although crown fires are often associated with strong winds, in this case winds of only 10 to 15 miles per hour, with some stronger gusts, were sufficiently strong to channel the flow up the canyon and produce the exceptionally intense crown fire that overran the crews. The question arose as to whether the burnout operation with the helitorch on the south side of the fire directly accelerated the high intensity run up Wallace Creek. Interviews combined with a careful inspection of burning patterns on a 1/24,000 aerial photo mosaic did not reveal any fire behavior process whereby the helitorch burnout could have accelerated the run up Wallace Creek. The photo mosaic showed a patchy pattern of burned and unburned areas between the helitorch burning at the confluence of Wallace and Owl Creeks and upper Wallace Creek. The burnout operation, however, probably contributed to the shelter incident by preoccupying the attention of some key overhead personnel for so much of the afternoon of August 29. The "eyes in the sky" reconnaissance that had been routinely available on previous days was not available during the critical time on August 29.

Early reports on the Butte Fire estimated that the fire traveled 2 miles up Wallace Creek in 15 minutes, or a spread rate of 8 miles per hour. This estimate now appears to be considerably higher than the actual rate of spread. Reconstruction of the fire front location at various times indicated that the average spread rate was closer to 2 miles per hour with a maximum of about 3½ miles per hour.

The safety zones that were bulldozed into the tractor line at the head of Wallace Creek made it possible for 73 firefighters to safely and effectively use their fire shelters and survive one of the more violent fire runs observed in the northern Rockies in 1985. But, as one crew foreman observed after the incident, "the best safety zone is one where a fire shelter is not needed." This conclusion deserves special emphasis whenever the Butte Fire is discussed.

Preventing Future Incidents

What measures can be taken to prevent such a life-threatening event from recurring in the future? If an indirect attack strategy is selected, then a fail-safe warning system must be in place to absolutely clear the line of personnel well in advance of a high-intensity run. Another approach in conifer forests is to select a direct attack strategy, build a line along the flanks of the fire from a well-secured anchor point, and attack the head of the fire only when fuels, weather, and topographic conditions allow firefighters to work safely.

Whatever the strategy selected, the fundamental principles of fire behavior and fire suppression should always guide decisions that affect the health and welfare of the firefighter. Despite the remarkable progress made in fire management in the past quarter of a century—better understanding of fire behavior, better trained and equipped fire crews, more flexibility in attack strategy—conditions like those experienced in the northern Rockies in the summer of 1985 call for extreme vigilance in all aspects of fire suppression. And the safety of the individual firefighter is always the top priority. ■

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Butte Fire Shelter Videotape Available

A 33-minute videotape on the "Butte Fire Shelter Deployment" is now available from the Boise Interagency Fire Center. Videotaped onsite interviews with shelter occupants just days after the incident vividly demonstrate the importance of every firefighter having a shelter, knowing deployment procedures, and caring for the shelter properly. The videotape provides an excellent supplement to Missoula Equipment Development Center's new training film on fire shelters. Copies of the videotape can be ordered from:

Bureau of Land Management
Boise Interagency Fire Center
3905 Vista Ave.
Boise, ID 83705

The tape is offered in the following formats:

1. Order No. NFES 1523 3/4" U-matic $22.64
2. Order No. NFES 1524 1/2" VHS 11.24
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An Application of NIIMS on the Uinta National Forest

Helen Woods and Lyle Gomm

Program assistant and chief, Branch of Recreation and Lands, respectively, Uinta National Forest, Provo, UT

Since the implementation of the National Interagency Incident Management System (NIIMS), local offices of Federal agencies and State and local agencies, have banded together to cooperatively manage community emergencies such as fire, floods, toxic spills, aircraft disasters, rescues, earthquakes, and riots. One of the specific cooperative ventures, a pump and hose-lay team, is described in this article to show how agencies are working together more effectively and efficiently under NIIMS.

Figure 1—*Cooperating agencies worked together to set up a pump and hose-lay team to help fight fires in the Uinta National Forest.*

Figure 2—*Equipment used by pump and hose-lay team.*

Many fires along the Wasatch Front of the Uinta National Forest occur in locations where they can be effectively suppressed using water from nearby lakes, streams, and irrigation canals or ditches. Most of these fires start in heavily used campgrounds and other recreation areas located in river and creek bottoms. The burning of ditchbanks on farms, debris burning, and other misuses of fire also contribute. In accordance with the NIIMS concept, the Uinta National Forest, the Bureau of Land Management, Utah Division of State Lands and Forestry, and Utah County have cooperatively organized a pump and hose-lay team to fight fires within their jurisdiction.

The pump and hose-lay team is a group of trained firefighters from the cooperating agencies who can effectively take advantage of available water sources to fight fires along the steep Wasatch Front and in areas that are often inaccessible to engines. This team is trained to work together dur-

ing the initial stages of the incident to set up the system. After the hose system is in place, the crew can then split into two three-person shifts and utilize other, untrained personnel to work along with them. The crew is also trained in the use of gravity-fed systems that are used if the water source is high or if a helicopter is used to fill a tank on a ridge and the fire lies below in a canyon.

The pump and hose-lay team is designed to provide initial and secondary attack on frontal slope wildfires within and adjacent to Utah County. The high-risk and flashy fuels located along the Wasatch Front require immediate and aggressive action once a fire is identified. Any fire in this area has potential to be threatening to life and property.

A trailer to house the unit was constructed by the Forest Service and is capable of carrying pumps and hose equipment needed to run hose 3,000 feet horizontally and 1,000 feet vertically (fig. 1-2). There are three large pumps, two Mark III pumps, and one Chrysler Flotopump. To augment the large pumps, the two smaller Mark III pumps (contributed by the Utah Division of State Lands and Forestry) are used to run smaller lines from relay tanks set up to help in moving the water uphill. The exact pump configuration, of course, depends on the situation and application. Four lightweight relay tanks are included, along with a much larger 500-gallon, open-top tank suitable for helicopter fill operations. Much of the hose and necessary fittings have been contributed by the Bureau of Land Management. Utah County took care of painting the trailer. Utah County has also worked with the Forest Service in training part of its strike team to operate the equipment and use the trailer.

The equipment carried on the trailer is suitable for pumping operations, but it can also be used with city fire hydrants. It can be used in remote or desert areas with either large tankers

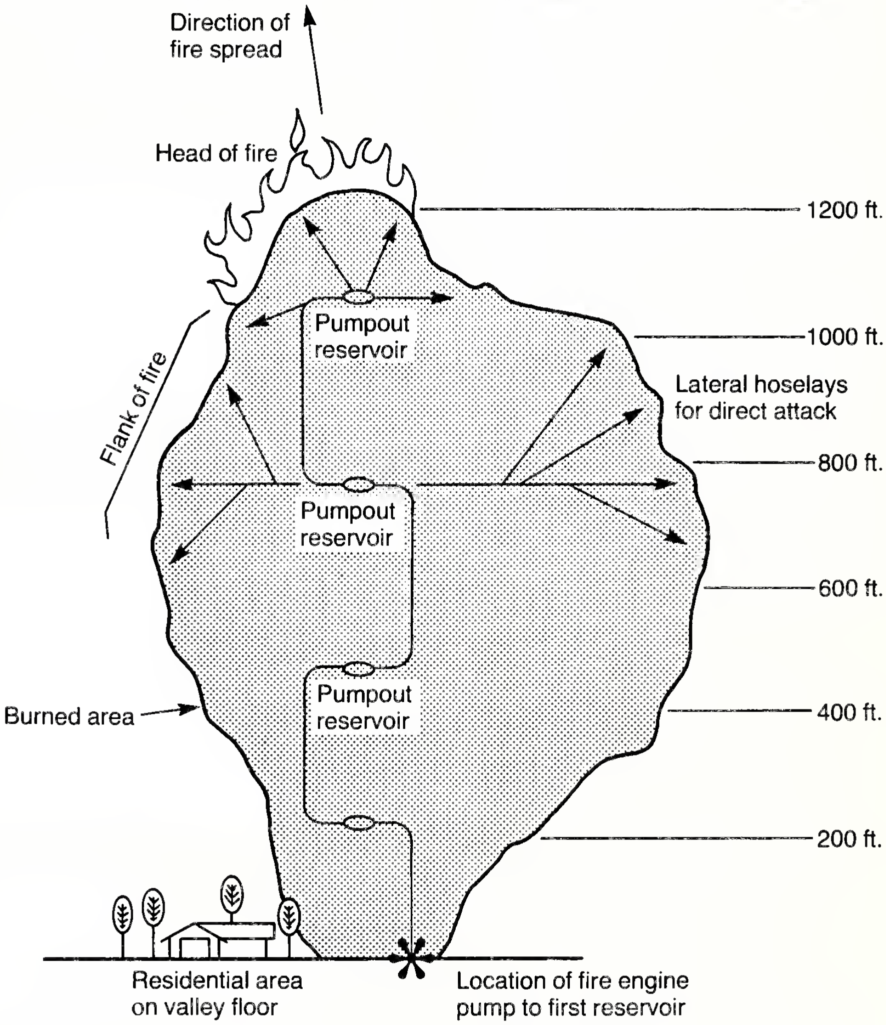

Figure 3—*Diagram of use of equipment to fight a typical frontal fire.*

or helicopter drops into artificial ponds. These alternative water sources would be more expensive than using a nearby lake or stream.

The equipment used by the team is designed to make water readily available up 1,000-foot vertical slopes. This is achieved through lightweight pumps, small reservoirs, and thousands of feet of linen hose. The equipment is designed to be backpacked up the slope as the fire develops. It is also designed for fighting the fire from within the burned area. In this way, direct attack can be made ahead of the fire without threat to firefighter safety (fig. 3-4).

Other pieces of equipment have been assembled, under the NIIMS concept, to supplement the hose-lay unit. The Interagency Incident Command Post trailer contains all necessary equipment for an efficient fire management operation. A military-type command and staff organization functions out of this trailer to handle incident objectives to which it is assigned (fig. 5).

During the fire season, the trailer is outfitted with a generator, lights, sleeping gear, and other personal gear for six crew members. The unit also contains radio equipment for communications to all cooperating agencies and functions as a backup unit to the central dispatch office located in the Utah County sheriff's office.

A personal computer will be housed within this facility to provide telecommunication and word processing capability. The computer will be used to store and retrieve the information necessary to manage a large fire organization, information on overhead personnel, fire crews, earth-moving equipment, aircraft, fire engines, and so forth.

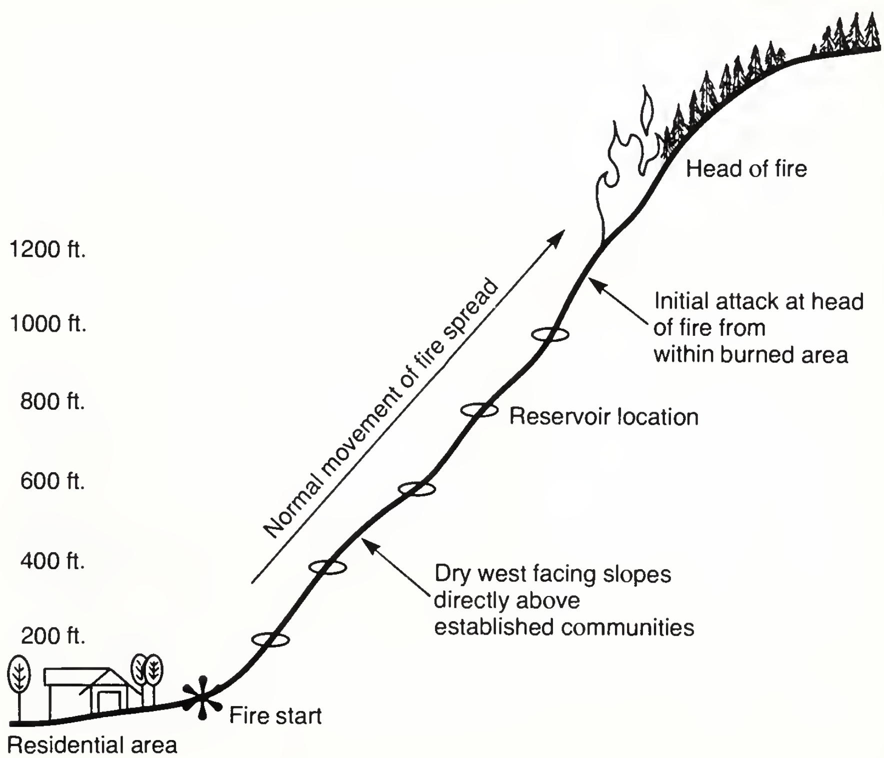

Figure 4—*Equipment used by the pump and hose-lay team is designed to make water available up 1,000-foot vertical slopes.*

In the Uinta National Forest, NIIMS is working and working well. The cooperating agencies are experiencing success in the joint management of fire and other community emergencies that may arise. The effective interagency cooperation shown in developing and maintaining the command post trailer and the pump and hose-lay team is evidence of the success, of the NIIMS concept.

Utah County firefighters are excited about the training they are receiving in fighting wildfires. Forest Service crews are eager to use the new equipment. Each contributing agency can see with pride the result of cooperation. ■

Figure 5—*Command post trailer organized under NIIMS concept contains equipment for efficient fire management operation.*

Current Status of BEHAVE System

Roger L. Eubanks, Roger L. Bradshaw, and Patricia L. Andrews

Fuels management specialist, USDA Forest Service, Washington, DC; computer programmer/analyst, USDA Forest Service, Boise, ID; and mathematician, USDA Forest Service, Missoula, MT

BEHAVE is a set of interactive, user-friendly computer programs that are used for site-specific fire behavior prediction. An overview of BEHAVE was given in a previous Fire Management Notes article by Richard C. Rothermel, "BEHAVE and YOU Can Predict Fire Behavior" *(5)*. That article included information on what BEHAVE can do, where BEHAVE applies, and how to make specific applications. This article will give information on the current status of the BEHAVE system, documentation that is available, how the programs can be accessed, and additional development that is underway.

Responsibility

BEHAVE was developed by USDA Forest Service Research personnel at the Intermountain Fire Sciences Laboratory (previously known as the Northern Forest Fire Laboratory). The Aviation and Fire Management Staff in the Forest Service Washington, DC, office has accepted BEHAVE as a national system. Local specialists trained in the BEHAVE system are responsible for providing users with assistance in operating BEHAVE. BEHAVE instructors have been trained in each Forest Service region and in other Federal agencies that have wildland fire management responsibilities. Others who have received training as instructors include State and university employees. This corps of instructors has responsibility for training additional BEHAVE users.

Documentation

The primary documentation of the BEHAVE system consists of two Forest Service Intermountain Station General Technical Reports (GTR). Burgan and Rothermel describe the FUEL subsystem *(3)*; Andrews describes the BURN subsystem *(1)*. Rothermel's GTR "How to Predict the Spread and Intensity of Forest and Range Fires" *(4)* provides the basis for his article "BEHAVE and YOU Can Predict Fire Behavior" *(5)* and Andrews and Burgan's "'BEHAVE' in the Wilderness!" *(2)*. The BEHAVE Terminal User's Guide is a quick reference for worksheets, codes, program structure, etc. It is printed in looseleaf format to allow for future updates.

The two GTR's and the Terminal User's Guide are available through the NWCG Publications Management System in Boise, ID.

Programs

The master copy of the BEHAVE programs is maintained on the USDA computer in Ft. Collins, CO. The source code is available to users who wish to use BEHAVE on their own computers. The programs are written in ANSI Standard X3.9-1978 Fortran. The largest program, FIRE 1, requires approximately 260K bytes to load on Data General MV/8000. BEHAVE is being successfully used on a variety of computers.

Forest Service users with Data General equipment will receive the BEHAVE programs and all updates through the regular Forest Service software update procedures. The local systems manager is responsible for deciding whether or not to place BEHAVE on the system. Those not using Data General may send a written request to Roger Bradshaw stating their name, address, and phone number. Requests for tapes should include the character set, tape density, blocking, labeling, tracks, record length, and a blank tape.

Modification of the programs to run on a local computer is the responsibility of the user. Users are also responsible for making sure that any local copies of the program match the master. Version numbers are used to indicate changes made in one or more of the BEHAVE system programs. A change in the tenth's digit indicates minor changes that correct program errors or enhance existing features; the one's digit indicates major changes such as the addition of new prediction models. At the time of this writing the version number of all three programs is 3.3.

A BEHAVE conference is on the conference system at the Ft. Collins Computer Center. The conference will be used to announce new versions of the programs, indicate necessary changes, and tell how to obtain updates. Users are responsible for monitoring the conference or making other arrangements for obtaining announcements.

Requests from outside of the United States are handled by Patricia

System	Subsystems	Programs	Modules
Behave fire behavior prediction and fuel modeling system	**Fuel** fuel modeling subsystem	**New MDL** initial fuel model development program	**Site** spread rate and intensity calculation module (site - specific input)
			Direct spread rate and intensity calculation module (direct entry of general input)
		TST MDL fuel model test and adjustment program	**Size** area and perimeter calculation module
			Contain attack force requirement calculation module
	Burn fire prediction subsystem	**Fire 1** prediction program	**Spot** maximum spotting distance calculation module
			Dispatch automatic linking of **Direct, Size and Contain**
		Fire 2 prediction program	Calculation modules to be added later

Subsystems, programs, and modules that make up the BEHAVE fire behavior prediction and fuel modeling system.

L. Andrews. She will see that foreign users are kept informed of updates. An attempt will be made to arrange for a single contact for each country. So far, BEHAVE has been sent to Canada, Australia, South Africa, Spain, Mexico, and Portugal.

Updates

A diagram of the current BEHAVE system design is shown in figure 1. The FUEL subsystem consists of the programs NEWMDL and TSTMDL. At this time the BURN subsystem has only the FIRE 1 program. However, a FIRE 2 program is being developed, and the FIRE 1 program is being expanded. FIRE 2 will include the following modules:

- MOISTURE—The fine dead fuel moisture model that is now in SITE. This model will allow table output for ranges of input parameters as well as graphic output showing diurnal variation.
- IGNITE—Probability of ignition.
- RH—Relative humidity and dew point from elevation; wet bulb and dry bulb temperatures.

The FIRE 1 program will be expanded as follows:

- SPOT—Addition of spotting distance from wind-driven surface fires.
- CONTAIN—Addition of containment by indirect attack.
- SCORCH—Scorch height.

The keywords LOG and NOLOG are in the current version of BEHAVE, but they are not described in the formal documentation. This description was added in response to user request. Because the BEHAVE programs are interactive, printing an entire session on paper is quite unwieldy. The LOG option saves only input listings and computed results in a file. When the session is complete, the user is reminded to print the file and then delete it. (The method of printing and deleting is a function of the user's computer and is not part of the BEHAVE system.) In this way a user can use a nonprinting terminal,

yet have paper printout of the important parts of the run. The next version of the BURN programs will also have the keyword COMMENT to allow user notes to be printed in the file.

Summary

BEHAVE has been an approved national system since 1984 and is currently being used for a variety of fire management applications. It is a dynamic system that is expected to change as new technology becomes available for field application. Watch for future articles in Fire Management Notes describing the updates and applications in more detail.

If you have any questions or suggestions, contact Roger Eubanks at:

USDA Forest Service
P.O. Box 2417
Washington, DC 20013
(703) 235–8666
FTS 235–8666

Program maintenance is performed by Roger Bradshaw, who can be reached at:

USDA Forest Service
3905 Vista Ave.
Boise, ID 83705
(208) 334–9458
FTS 554–9458

Requests from outside the United States should be directed to Patricia L. Andrews at:

Intermountain Fire Sciences Laboratory
P.O. Box 8089
Missoula, MT 59807
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Crew Mobilization: What's the Next Step?

Stephen W. Creech

State fire coordinator, Indiana Department of Natural Resources, Division of Forestry, Martinsville, IN

This is the second part of a two-part article dealing with interagency fire crew mobilization. Part 1 dealt with the preparation and planning that are necessary to pull personnel together in the most efficient manner to meet mobilization deadlines. Part 2 will deal with fire camp, fireline operations, and demobilization. This information is intended to address some of the problems that the crew boss/strike team leader, and squad boss, as well as, rookie and veteran firefighters, may encounter and to offer suggestions to make the assignment as positive an experience as possible. We must all remember that our role in these assignments is to serve the host agency and not vice versa.

Part I left off as the crew boarded the aircraft for the fire assignment. We will now pick up as the plane lands, and we begin our assignment. However, you and your crew have not already encountered lengthy delays you had better prepare yourselves for the inevitable. These sometimes lengthy and always frustrating delays are probably the number one enemy of good crew morale. Dealing with the possibility of delays at the beginning can prevent more serious problems later on.

What I would like to do now is deviate from the story line a bit to look at some of the National Interagency Fire Coordination Center (NIFCC) statistics for 1985. There were approximately 83,000 reported fire starts that burned more than 2,975,000 acres. To combat these fires required in excess of 25 class I teams, 2,510 miscellaneous overhead, 276 category I crews, 1,010 category II crews, 749 smokejumpers, 473 fixed and rotary wing aircraft (fire suppression aircraft), $9,721,000 worth of catering services, $1,194,000 worth of shower facilities, and $8,500,000 worth of charter and contract aircraft. In addition, more than 50,000 firefighters were moved throughout the country. These statistics do not include ground transportation or the assistance provided from the military.

I think that now you can appreciate a little better why there may be some unexpected delays and perhaps be able to deal more effectively with the questions fired at you from the crew. I will now jump ahead a bit and assume that we have safely reached fire camp.

Fire camp is always a very hectic place. Don't expect to be greeted at the gate and shown to your quarters. The first thing to do is to let someone know that your crew has arrived. The fire camp may be operated under either the National Interagency Incident Management System (NIIMS) or the Large Fire Organization (LFO). The reporting procedure will vary. Under NIIMS, the strike team leader/crew boss or the crew representative should first report to the planning section, resource unit leader (RESTAT). Under LFO the crew boss would report to the maps and records section.

You should understand that your crew members may be utilized in one of several ways. They may be considered a single resource, they may be joined with another crew and formed into a strike team, or they may become part of a task force. How they are utilized will depend upon the needs of the incident and may change according to changing needs.

Next, crew manifests and timesheets must be taken to the finance section (this is the same under both NIIMS and LFO). A close check should be made here to see that a timesheet is made out for each member of the crew. A little extra effort here can prevent problems later on. The last stop will be to check in with the staging area manager (NIIMS) or the camp officer (LFO). Here you will be assigned an area to assemble your crew. Once this area is established, place a sign (one may be provided) on the perimeter showing the crew name and crew leader. This area will become your home for the next several days.

The strike team leader/crew boss must decide if the crew is sufficiently rested, considering travel time and rest opportunities, to accept a line assignment. The incident may not require that your crew be placed on the fireline immediately, but if you are asked to assume a fireline role, it is your responsibility as leader to evaluate the crew's ability to safely carry out out the assignment. The crew's well-being depends on you. Regardless of whether you are immediately assigned to line duty, there are certain things that must be routinely taken

care of concerning your personnel.

Your crew will do a better job if they are happy and healthy. Prevention is the key to success. Let's look at some simple yet effective preventive measures:

1. **Hold briefings.** Your crew members want to know what is going on. They are not looking for detailed information—they just want to know what is happening and what is their role. Where are they? Where will they be going? What is the fire doing? What is the terrain like? How long is the work shift? Tell them what you know. Don't lie and don't speculate. Personnel who feel informed will have fewer morale problems than those who are kept in the dark.

2. **Information dissemination.** Make sure good information gets back to the home unit and that the home unit passes the information along to family and friends left behind. The good public relations that can be obtained from fire assignments goes a long way to ensure that the crew members will be available the next time they are needed. As long as the firefighting personnel feel that their best interest is being considered, they will remain happy and productive. It will be necessary to plan ahead how and when family and friends will be contacted. The home unit has the responsibility to disseminate timely information. Planning is the key to success here.

3. **Proper camp habits.** Insist on good eating, rest, and hygiene habits. Failure to adhere to any one of these can spell disaster. The need to observe this must be stressed at the early briefings. Individual counseling may be necessary in some cases. Since the fire situation can change very rapidly, it may be necessary to alter plans. For that reason it is suggested that a schedule be established while the crew is in camp, so that someone is at the designated crew area at all times. This will greatly improve response time and will eliminate unnecesary delays.

Note—As a strike team leader/crew boss you may be faced with a situation where your crew is allowed to go into a nearby town. This can happen during staging or during 24-hour on/24-hour off work cycles. You are still responsible for your personnel, and you have the ultimate authority to approve or deny the privilege. It is not an easy decision and can prove most unpopular.

4. **First aid.** First-aid problems must be attended to immediately. Problems can occur while on the line or in camp. Don't assume the problem will go away. Make sure prompt medical attention is provided. If first-aid is administered on the line, have the individual report to the first-aid facility upon return to camp. Document any problems to assist in future claims.

5. **Personal problems.** Action here must be swift and firm. You may need help in dealing with certain matters so don't be afraid to ask. Morale or attitude problems, if left unchecked, can rapidly spread to other personnel and literally disable a crew. All members of the crew should feel as though they can discuss their problems openly at any time.

6. **Safety.** Safety is one area that can never be stressed enough. Safety in camp, on the way to the fireline, and on the line must be constantly monitored. Unsafe conditions should be corrected or brought to the attention of others. Don't think that the Safety Officer can catch every safety problem. Safety is the responsibility of all firefighters, but particularly those in a supervisory position.

7. **Performance evaluation.** It is the crew member's responsibility to obtain crew performance evaluations from the unit supervisors they are working for. Don't assume that the evaluations will automatically be completed for you. The crew performance evaluation is proof of how well your crew performed and should point out areas that need improvement. These evaluations can mean the difference between being utilized properly and not being utilized at all. Incident commanders are looking for personnel who can do the job. The evaluation is your proof that you and your crew can perform satisfactorily.

The key to success on any fire assignment is to maintain control and work as a team (fig. 1). Work to the best of your ability, and don't be afraid to admit that you can't do something or that you are not properly trained or qualified. Firefighting is a dangerous profession and the more we all know and the more we work to-

Figure 1—*The fire crew's performance will be reflected in a crew performance evaluation.*

gether the safer and more effective we become.

We will now assume that our assignment is completed and we have gone to demobilization status. Once you have fulfilled your time requirement or the emergency has subsided, you must be released back to your home unit. The process of checking out is much the same as checking in. You will be required to turn in any accountable, issued gear. You will have to verify, sign, and take charge of timesheets. You must obtain copies of any request for treatment forms from the first-aid area. Your camp area must be cleaned up, and you must sign out through RESTAT. It may seem harder to get out of camp than it did to get in.

Once you are sure of your demobilization plans, particularly flight plans, it is a good idea to make one last contact with your home unit to assure that someone will be there to meet you. Remember that on a large-scale operation things can change and messages and arrangements occasionally get messed up. It may not always be possible, but a short call just prior to demobilization may save a lot of confusion later on. You need to indicate mode of transportation, the carrier's name, the destination (airport and gate location if known), and approximate time of arrival. You might also plan to have a meal waiting just in case. This kind of planning isn't foolproof, but it sure helps smooth out the process.

Once you arrive at your official duty station, you still have a few loose ends to tie up before you can close the books on this incident. You need to reclaim the fire gear from your personnel. Any materials that came from the fire cache should be put back, or plans should be made to replenish depleted items. If it is feasible, have the crew members acknowledge that they arrived home safely. A quick phone call back to the home office or to the strike team leader/crew boss is all it takes.

You should plan to hold an assignment critique when time allows, preferably while the incident is still fresh in everyone's mind. The critique should look at the following areas:

1. **Incident management.** You should include an evaluation of each of the phases of the assignment. Examine mobilization, staging, fire camp, line assignment, safety, organization, and demobilization. You are looking for items, both good and bad, that could make future assignments operate more efficiently.

2. **Personnel evaluation.** You need to look at all of your fire personnel and evaluate their performance on the assignment. Did they follow orders? Were they team players? Were they good representatives of your home unit? Did they perform up to standard? Could they be considered for transfer to a different position (for example, firefighter to squad boss, or

squad boss to strike team leader/crew boss)? Were they physically qualified? Poor performers should be removed from the roster and not allowed to participate in future assignments until shortcomings are rectified. Remember the whole team's evaluation may hinge on one person's actions.

3. **Training needs.** You should evaluate training needs very closely. Was there a need for training that you or your crew have not had? Do certain personnel need a refresher course? Is there a need for more advanced training for some of your personnel? Training is an ongoing consideration. It is needed both to maintain proficiency and to prepare personnel for advancement.

Once you have completed the critique you should make copies available to your home office, the sending agency, the receiving agency, and each of your personnel. The critique should be objective and honest. You should immediately develop a plan of action to correct those areas within your jurisdiction that need improvement. Your efforts here will pay off on the next assignment for everyone.

If you are a veteran leader you should have picked up some helpful reminders from this article. If you are a veteran firefighter you should have gained some useful information in case you are ever given the responsibility to lead your own crew/strike team. If you have only dreamed of going on an out-of-state fire assignment you should have a better appreciation of what to expect and also a better understanding of what goes into such a complex undertaking. ■

Late-Winter Prescribed Burns to Prepare Seedbeds for Natural Loblolly–Shortleaf Pine Regeneration—Are They Prudent?

Michael D. Cain

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Density, percent stocking, and total heights of first-year loblolly and shortleaf pine (Pinus taeda *L. and* P. echinata *Mill.) seedlings were measured one growing season after a late-winter prescribed burn in uneven-aged pine stands in southern Arkansas. These data were compared with data from the same year for an area where there had been no prescribed burning. Although a partial seed catch on the late-winter burn area produced significantly fewer pine seedlings, the burn coincided with a bumper seed year that resulted in a high-density, well-stocked crop of pine seedlings after one growing season.*

Introduction

The use of prescribed fire for seedbed preparation in natural regeneration of loblolly and shortleaf pine (*Pinus taeda* L. and *P. echinata* Mill.) is widely practiced throughout the South. The recommended technique is to use a winter burn to reduce fuel accumulation and follow up with one or more hot summer burns to topkill small hardwoods and expose mineral soil *(7)*. To maximize seed catch, prescribed burning should be done just before seedfall (*8, 16*). Such timing of prescribed burns will provide a mineral soil seedbed yet will not destroy the current year's seedfall.

Natural seedfall for loblolly pine begins in October and may persist into spring. However, seedfall monitoring in North Carolina has shown that 71 percent of loblolly seeds fall by the end of November *(1)* and that 84 percent of all loblolly seeds fall before January (*13*). Similarly, in south Arkansas, Grano (*12*) found loblolly-shortleaf pine seedfall to be 77 percent complete by the end of November and 92 percent complete by the end of December. Chaiken (*6*) monitored loblolly pine seedfall for 6 years in South Carolina and noted that 92 to 100 percent of all viable seeds were disseminated by February 1.

On the basis of these findings, an effort should be made to coordinate the timing of prescribed fires for seedbed preparation with natural pine seedfall. For example, Lotti and others (*14*) surmised that if a preharvest prescribed winter fire takes place after the main seedfall in loblolly pine stands, almost full dependence must be placed on the following years' seed crop for pine regeneration. The reasoning has been that pine seed on the ground will be destroyed by the fire.

Yet, fuel and weather conditions for prescribed burning in the South are often most favorable during the winter when cold weather fronts pass through with steady north winds *(8)*. It is therefore appropriate to investigate the effect of a late-winter prescribed burn on subsequent pine seedling establishment from a current year's seed crop.

Methods

Data for this investigation were obtained from two active research studies on the Crossett Experimental Forest in south Arkansas. Soil on the study areas is Bude silt loam (Glossaquic Fragiudalfs) with a site index of 85 to 90 feet for loblolly pine at age 50 years.

Study A—The purpose of this study was to assess the effects of prelogging hardwood control for establishment of natural pine regeneration. When the study began, the stand contained about 100 square feet of pine basal area per acre. On four 0.25-acre plots all hardwoods having a groundline diameter of 1 inch or larger were stem-injected with picloram (Tordon 101R) in March 1983. Herbicide spotguns were used to treat four other 0.25-acre plots with hexazinone (Velpar-L) using 4 pounds a.i. per acre on a 4- by 4-foot grid in April 1983. A basal area reduction harvest of overstory pines was done in July and August 1983, removing an average of 6,000 board feet per acre (International ¼-inch rule). This reduction left a 76-year-old even-aged stand of loblolly–shortleaf pines averaging 68 square feet of basal area per acre in 28 trees per acre. Since the intent of the study was to facilitate pine regeneration from natural seedfall, data from the study were used as a standard for comparison with data taken from the area where late-winter prescribed burning was done in study B.

Study B—The purpose of this study was to determine the effect of overstory pine basal area and cyclical

burning intervals on establishment and growth of pine regeneration in uneven-aged stands of loblolly–shortleaf pine. Before the study, these stands contained over 100 square feet of pine basal area per acre. Prescribed winter burns were first conducted on January 14 and 15, 1981. In August and September 1981, all hardwoods 1 inch in diameter at breast height (d.b.h.) and larger were stem injected with Tordon 101R. Merchantable pines were cut in June and July 1982, removing an average of 7,000 board feet per acre (International ¼-inch rule). This left a balanced uneven-aged structure with specified basal area averaging 72 square feet per acre in 110 trees per acre. Plots remained undisturbed after the 1982 harvest until January 31, 1984, when a second prescribed burn was conducted (table 1). Pine seedling establishment following the second late-winter burn is the subject of this investigation. Seedling data were taken within 2.5-acre gross plots where residual basal area averaged 78 square feet per acre in the fall of 1984.

An estimate of pine seed production was obtained from 40 seed collection traps (1/20 milacre each). These traps were on all 16 plots in study A and on 24 plots at 5 other locations in uneven-aged pine stands on the Crossett Experimental Forest. Seed counts were taken once a week from October 1983 through February 1984 (22 weeks). All collected pine seeds were cut open, and those containing fully grown, firm, undamaged tissue were judged as potentially viable *(3)*.

Table 1—*Average conditions during prescribed burning on January 31, 1984*

Variable	Measurement
Precipitation:	
Time since last accumulation	8 days
Amount	1.22 inches
Air temperature during burn	34 to 50 °F
Relative humidity during burn	70 to 24 percent
Wind:	
Direction	From the south
Velocity	3 miles per hour
Time of day	10 am to 4 pm CST
Type of burn	Back and flank fires
Fine fuel moisture[1]	12 percent
Mean fireline intensity[2]	92 Btu/ft•sec
Range in fireline intensity	47 to 127 Btu/ft•sec
Estimated ground coverage by fire	83 percent

[1]Determined from fuel-moisture sticks at midday

[2]Fireline intensity (I) *(5)* was calculated from over 100 ocular estimates of flame length (L_f), in feet, observed during the prescribed burns: $I = 5.67 L_f^{2.27}$

In October and November of 1984, pine seedling counts were made one growing season after seedling establishment in both study A and study B. Nine 0.3-milacre circular quadrats were systematically established within the interior 0.1 acre on each of eight 0.25-acre gross plots in study A and on each of six 2.5-acre gross plots in study B. The number of pine seedling within each quadrat was counted and total height of every fifth seedling was measured to the nearest 0.1 foot. Although older pine seedlings could have been found on plots in study B, only first-year pine seedlings were encountered. The prescribed burn in January 1984 had apparently eliminated all previously established pine seedlings.

A *t*-test for unpaired plots between study A (8 plots) and study B (6 plots) was used for comparing mean density, percent stocking, and total height of first-year pine seedlings, as well as overstory pine basal area. All statistical tests were conducted at the 0.05 level of significance. Arc sine transformation was used in analysis of percent stocking.

Seed Crop

Total cumulative pine seedfall between October 1, 1983, and March 1, 1984, averaged over 1,170,000 seeds per acre with 81 percent considered sound. According to Baker and Balmer *(2)*, a good seed crop for loblolly pine is more than 80,000 sound seeds per acre, and an average crop is between 30,000 and 80,000 sound seeds per acre. Judging by these standards, the 1983–84 seedfall was a bumper crop. Based on the 22-week

collection period, pine seedfall was more than 75 percent complete by December 1 and 90 percent complete by the time of the January 31 prescribed burn.

Even though seedfall was nearly complete before burning in study B, the bumper seed year provided sufficient seeds after burning for ensuring natural pine regeneration. Ten percent of the sound seed crop, or nearly 95,000 sound seeds per acre, was collected in traps after January 31. Thus, in this bumper seed year, 10 percent of the crop was equal to an entire seed crop in an average seed year. Also, some additional seeding probably occurred after the March 1 termination date for seed collection.

Seedling Establishment

As would be expected, study area A, which had been site prepared for natural pine seeding prior to seedfall, had substantially more pine seedlings after 1 year when compared with study area B, which had received only partial seeding following the late-winter prescribed burn. First-year seedling density in study A, where there was a complete seed catch in the winter of 1983–84, averaged nearly 63,000 seedlings per acre. This figure was significantly higher than the nearly 21,000 seedlings per acre in study B with the partial seed catch (table 2). Stocking of first-year pine seedlings in study A averaged 100 percent, again significantly higher than the 89 percent stocking in study B (table 2).

Table 2—*Comparison of pine seedling establishment on seedbeds prepared before seedfall (A) and on seedbeds prepared after the bulk of seed had fallen (B)*

Seedbed treatment[1]	First-year pine seedlings: Density	Stocking	Total height	1984 merchantable pine basal area
	Stems/acre	*Percent*	*Feet*	*Square feet/acre*
A	62,979 a[2]	100 a	0.46 a	70 a
B	20,607 b	89 b	0.36 b	78 b[3]

[1]A = Hardwood control + logging; B = Late-winter burn.
[2]Columnar means followed by the same letter are not significantly different at the 0.05 level.
[3]Estimated from 1982 postharvest inventory *(9)*.

Total height of first-year seedlings in study A averaged 0.46 feet, significantly taller than the first-year seedlings of study B, which averaged 0.36 feet (table 2). The additional 8 square feet of basal area in the overstory pines and higher stem density of merchantable pines in study B resulted in more shade and subsequently less growth of pine seedlings. Brender and Barber *(4)* reported that the level of pine overwood shade, measured by the height to live crown, ranks with overwood density as a major factor affecting the growth rate of loblolly pine seedlings and that survival and growth of understory pine seedlings are poorest under low overwood shade. Crown heights of the old-growth overwood in study A were taller than those of the uneven-aged overwood in study B.

Appreciably fewer pine seeds were required to produce a seedling in study B (5 seeds per seedling) compared to study A (15 seeds per seedling). Seeds that lay on the ground from early October until germination the following spring were available to any number of predators such as insects, birds, and woodlot mammals. Pine seeds that fell to the ground following the late-winter burn were available to predators for a much shorter period of time before spring germination. There are two possible sources of pine seedlings that arise on burned areas when burning is done after the bulk of seed has fallen. According to Chaiken *(6)*, either new seeds are disseminated after the fire or seeds that had lodged in sheltered or protected areas on the ground where they were not destroyed by fire were still viable.

Density and Stocking Recommendations

In uneven-aged management of loblolly-shortleaf pine, the recommended density for the submerchantable stand (≤4-inch d.b.h. classes) is 500 to 700 pines per acre *(10)*. On

clear-cut areas in even-aged management, it is desirable to have between 1,500 and 2,500 loblolly-shortleaf seedlings per acre the first year after establishment from natural seedfall *(11)*. Percent stocking is another criterion for judging the success or failure of natural pine regeneration. According to Trousdell *(15)*, areas that contain 90 percent stocking of loblolly pine seedlings from natural seedfall are considered well stocked.

In the investigation, after the late-winter prescribed burns in uneven-aged stands of loblolly-shortleaf pines during a bumper seed year, sufficient seeds were available to result in a high-density, well-stocked crop of pine seedlings. Although exact periodicity of bumper seed crops cannot be predicted, better than average or abundant seed crops of loblolly pine can occur at 2- to 4-year intervals *(13, 17)*.

Summary

When managing for natural loblolly-shortleaf pine regeneration using seed tree, shelterwood, or selection (uneven-aged) cutting methods, timing of seedbed preparation can be a critical consideration. Late-winter prescribed burning for seedbed preparation may result in an insufficient supply of viable seeds for regeneration purposes if done in poor to average seed years. For example, in this investigation, percent stocking and density of loblolly-shortleaf pine seedlings established following a late-winter prescribed burn were significantly less than stocking and density of seedlings on areas undisturbed during seedfall. Even so, a bumper pine seed crop that coincided with the late-winter burn resulted in a pine seedling stand that met or exceeded published recommendations for both adequate stocking and density.

These data suggest that land managers who rely on prescribed burning to prepare seedbeds in advance of natural pine seeding in the South can possibly extend the burning season through January during bumper seed years and still obtain adequate pine seed catch for regeneration purposes. ■

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